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Anisotropic Magnetoresistive Transducers on the Basis of a Self-Aligned Structure

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Abstract—A new design of anisotropic magnetoresistive structures, in which the shape of ferromagnetic elements repeats the shape of nonmagnetic conducting shunts, is proposed in order to increase sensitivity. Numerical simulation taking into account the nonuniform distribution of magnetization shows that self-aligned structures have a significantly higher sensitivity than classical "barber-pole" structures. Presumably, this advantage can be explained by the nonuiniformity of the magnetization in self-aligned structures, which compensates the influence of irregularity of the electric-current distribution.

Keywords: anisotropic magnetoresistive effect, magnetic field sensor, magnetic films, self-aligned structure

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INTRODUCTION

Magnetic-field transducers based on the anisotropic magnetoresistive effect (AMR effect) are of significant interest and widely used for magnetic-field measurements. The basic elements of such transducers are AMR structures in the form of a magnetic film (most frequently, of permalloy) with contacts [1]. The most widely used structure consists of a permalloy (FeNi) magnetic film with shunting strips of conducting material applied to it at an angle of 45° (the so-called "indented" structure or "barber-pole"). In this manner, an odd transmission characteristic with a sufficiently long linear section is formed (Fig. 1) [2]. The most important parameter of AMR structures, which determines their ability to solve certain problems, is sensitivity [3], which is substantially influenced by the parameters of the magnetoresistive film, in particular, the magnetization distribution and the value of the anisotropic magnetoresistive effect.

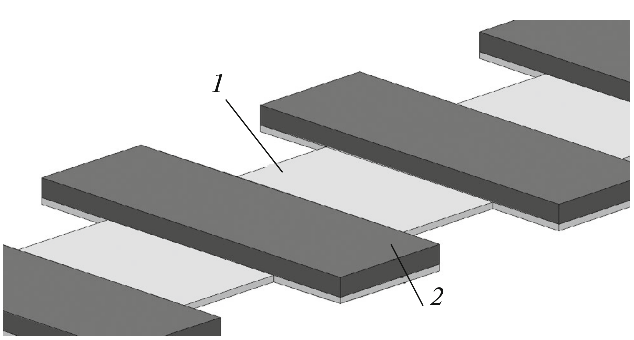

Fig. 1. Schematic of an aligned magneto-sensitive element: (*1*) permalloy and (*2*) aluminum.

PRODUCTION OF THIN MAGNETIC FILMS

Upon the magnetron evaporation of permalloy ($Ni_{80}Fe_{20}$) onto a $Si/SiO_2/Si_3N_4$ substrate (power of 150 W, target diameter of 100 mm, evaporation time of 300 s, magnetron–substrate distance of 112 mm, Ag pressure of 0.5 Pa, substrate temperature of 270°C), a 35 nm-thick film with nonuniformity of the surface resistance (R_S) distribution over the plate of less than 5% was obtained. The AMR effect detected in these films immediately after evaporation was 2.7%. The coercive force was ~2.2 Oe, and the anisotropy field was ~7.6 Oe (Fig. 2).

MATHEMATICAL MODELING

On the basis of the films obtained, an AMR sensor with the classical barber-pole structure and a sensitivity of up to 23.7 (mV/V)/(kA/m) was created [5]. Analysis of the magnetization distribution in this structure with using the micromagnet model gives an almost uniform distribution (Fig. 3a). However, if we assume that the shape of the magnetic element repeats

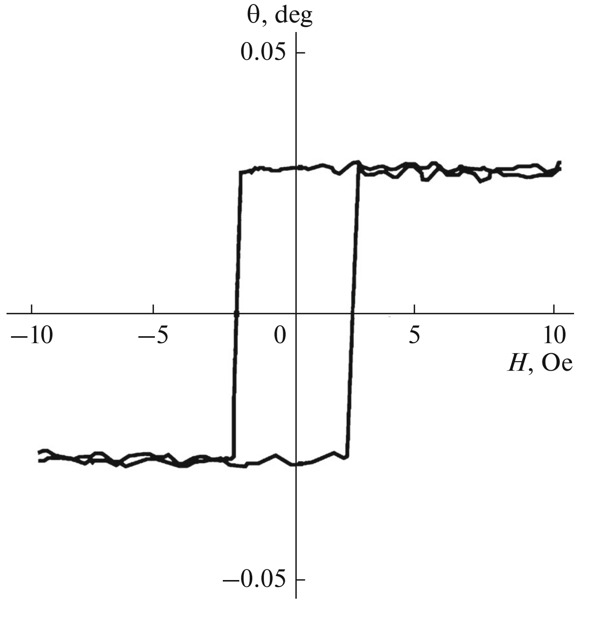

Fig. 2. Hysteresis loop of a permalloy plate along the easy magnetization axis.

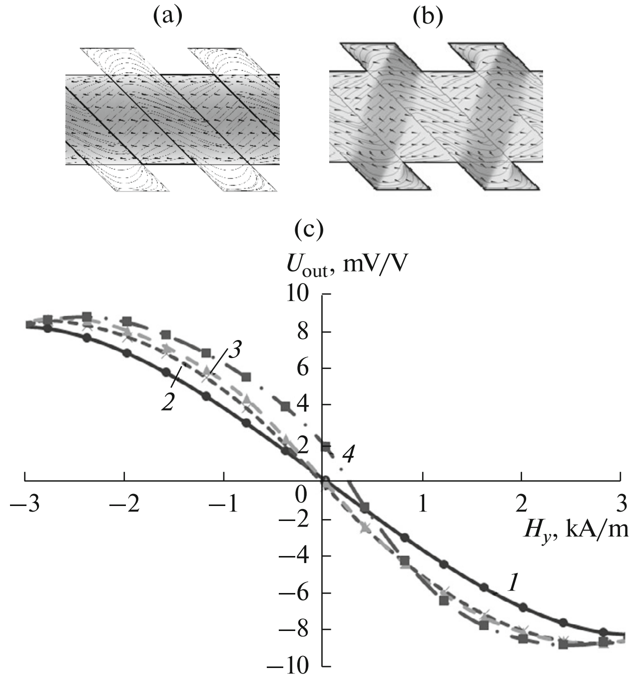

Fig. 3. Distributions of the magnetization and lines of current in (a) traditional and (b) aligned structures. The color gradient reflects the value of the X-component of magnetization; vectors of local magnetization are represented by arrows. Solid lines represent the lines of current. (c) Theoretical dependence of the output characteristics of transducers on the overhang parameter h = (*1*) 0, (*2*) 3, (*3*) 4, and (*4*) 6 μm.

the structure of the conducting shunt lying on it, the distribution becomes significantly nonuniform (Fig. 3b). Such a structure may be called self-aligned.

Mathematical modeling of the proposed AMR transducer was performed with the following characteristics of sensitive elements (Fig. 1): length of the magnetoresistive strip of 200 μm, the width of the strip varies from 10 to 40 μm, and the distance between the shunts is 6 μm. The overhang h of the elements of the nonmagnetic conducting layer also varies from 0 to 6 μm.

The magnetization distribution was calculated using the micromagnetic model [4], based on the Landau–Lifschitz–Gilbert equation.

RESULTS AND DISCUSSION

The obtained magnetization distributions in the structures with classical (Fig. 3a) and self-aligned (Fig. 3b) geometries confirm the assumed emergence of periodic irregularities of the magnetization distribution in self-aligned structures. Analysis was performed to estimate the influence of these irregularities in the sensitivity of the structures. The results are represented in Fig. 3c by the output characteristics of structures for different values of parameter h. The value $h =$ 0 μm corresponds to the structure with the traditional geometry; the shape of the curve agrees with the experimental data [5–8] for traditional AMR transducers. We can see that, as the overhang h increases from 0 to 3 μm, the sensitivity of the structure increases by ~70%. However, a further increase in h from 3 to 6 μm leads to a negative effect: the displacement of the zero-crossing point without an increase in the sensitivity. At negative values of h (a well), the sensitivity decreases. The optimal configuration of the self-aligned structure corresponds to $h = 3$ μm.

Thus, we have demonstrated the possibility of a significant increase in the sensitivity of AMR transducers by using self-aligned structures, without changing the technology of production.

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